

Summary and Inflammation (P.D.)

Ackn: SOCAL TTF Momentum Group

→ Momentum Transport

- something old → ~ con physics
ITG, DW, etc

- something new → vector → Π (transport)
Reynolds Tensor

- "stresses" understanding of:

→ cross phase

- Π structure $\langle \tilde{v}_i \tilde{v}_i \rangle \rightarrow$ fluid

- $\langle \tilde{v}_i \tilde{\sigma}_i \tilde{\phi} \rangle \left\langle \frac{d\tilde{v}_i}{dt} \right\rangle \rightarrow$ kinetic
(// acceleration)
sheared

* → 'symmetry breaking'

- $\langle v_E \rangle'$
- poloidal asymmetry } → edge !
etc. and E↔C coupling

- studied intensively in solar, astro, climate, oceanography, atmospheric

⇒ good source for outside Review speakers

→ structure of E Momentum Flux $\left\{ \left\langle \sigma_r \sigma_r \right\rangle, \left\langle \sigma_r \sigma_\theta \right\rangle \right\}$ 2

$$\Pi = -\chi_y \partial \langle v_{ii} \rangle + \nu \langle v_{ii} \rangle + S' \quad \text{(new)}$$

$\sim \chi_i$
 $\neq \chi_i$

convective
 TEP $\rightarrow \nu v_{ii} / B^3$
 advected
 thermo-electric
 (Yoshida)

"Residual Stress"
 $\left\langle v_e \right\rangle, \partial n, \partial T \dots$
 cross phase crucial

→ dependent upon mode propagation, symmetry breaking, resonant vs. non-resonant, etc.

→ Issue: How think 'beyond D, ν '?

i.e. → Perturbation experiments (dual) in $D \nu$, and $\partial T, \partial n$ — HARD
 — "offset" (Solomon)

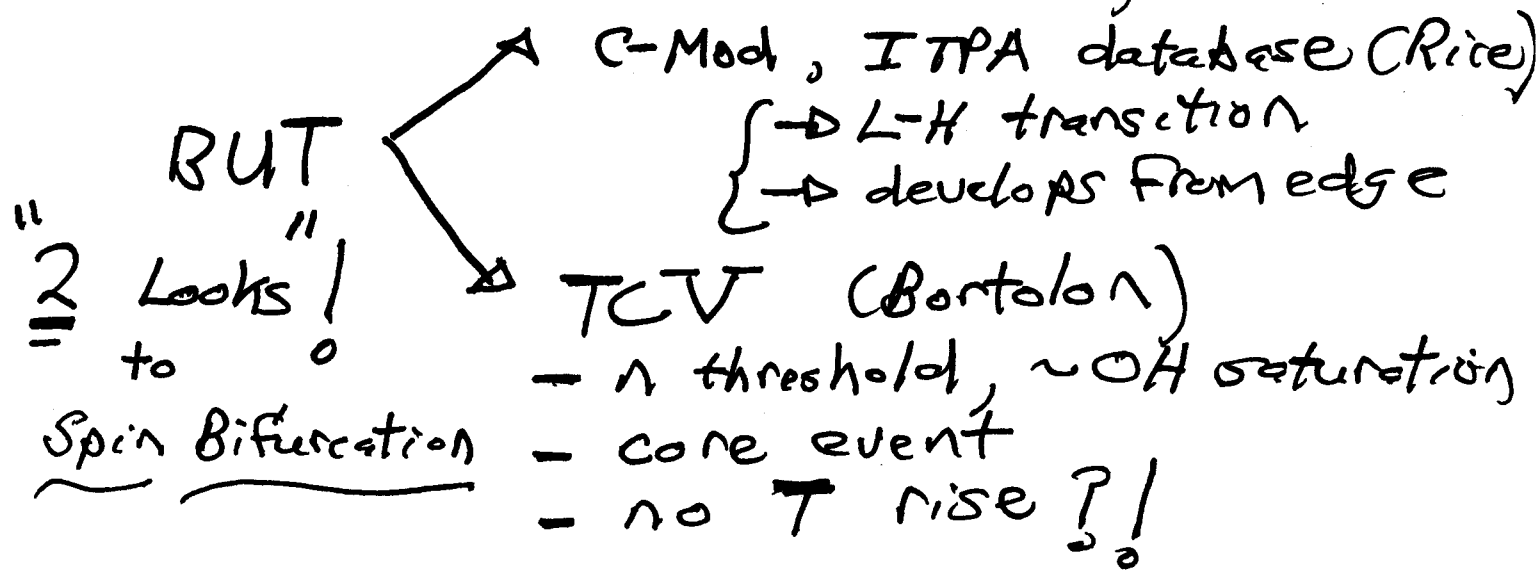
→ Issue: How address cross-phase? — (Hida (98))
Basic Experiments??

→ Intrinsic Rotation

→ the big mystery

→ frequently linked to $\langle V_E \rangle'$ in theory

→ "look" of a bifurcation



→ Cartoon Summary of Theory

critical parameter $\sigma \sim (V_{ph}) \langle V_E \rangle' \propto I$

σ residual stress mode ($\alpha \sim 2$)

→ C-Mod → transport bifurcation via V_E'

→ TCIV → V_{ph} 'bifurcation', $\langle V_E \rangle'_{inst}$

("spin" ≠ "transport")

Hysteresis → turbulence spreading?

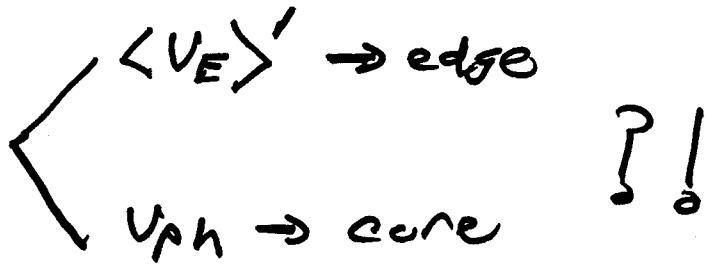
Ackn: { Garbet
Sarazin
Naulin

4

→ Issues:

① Other types?

- dual behavior
- spin bifurcations



- ITB formation → \hat{S} enters /
(need re-visit theory)

② Fluctuation Studies ?

- V_{ph} change → resolution (?)
observable
- $\langle V_E \rangle'$ → " "
- induced reduction
- elucidate physics of cross-phase

③ Perturbation Experiments

- spin-up bifurcation fronts ?!
track via fluctuations

- elucidate:

- "true" bifurcation? → SLOW TRANSITIONS
- $T \rightarrow \infty$ at transition?
- hysteresis?

Perturbation, cont'd

→ explore $L \rightarrow H \rightarrow L \dots$ cyclic perturbation

④ Edge as origin of $\left\{ \begin{array}{l} \text{symmetry breaking} \\ \text{B.C.'s} \\ \text{source} \end{array} \right.$

→ many candidates
to explore.....

Edge Plasma Dynamics crucial to Spontaneous rotation

- ▶ Symmetry breaking evident at edge (!)
 - $\langle V_E \rangle$ -> L-H transition
 - X-point configuration, field ripple (JT60-U, TS), other magnetics...
 - Poloidal plasma asymmetries, strong ballooning, GAMs,...
- ▶ Boundary condition (!?)
 - Neutral friction => 'no slip' (TCV)
 - Neo-classical polarization effects ?
 - Er structure in/out LCFS (Hinton)
 - Direct particle, wave momentum losses
- ▶ Source (!?)
 - **C-mod** strongly suggests spin-up initiated at edge [Lee, PRL '03]
 - SOL flows (c.f. C.S. Chang, *et al.*)
- ▶ Stationarity (!?)
 - Edge is strongly turbulent, bursty and intermittent (Boedo, Zweben,...)
 - Momentum transported via blob ejection events (Myra, Coppi)

→ Core Rotation Profiles ↔ Evolution

Issue: Pinch (rather complicated)

- TEPA → $\begin{cases} V_n \\ V_v \end{cases}$ correlated, strongly
 - ⇒ dual $\begin{pmatrix} \Lambda \\ V \end{pmatrix}$ perturbation experiments
 - ⇒ compare $(DT/\Lambda) - (DT/T)_{crit}$ cases
- V_{*e} (i.e. CTEM) dominated regime is clearest case ⇒ electron heating + perturbation?
- can experiment elucidate what is "natural" variable?

Issue: ∇V_ϕ as double agent?

- $\langle E_r \rangle$ → 'good'
- shear flow instab → 'bad'
- can DIII-D elucidate differences between Hybrid Mode scans and 'Solomon' scans, even qualitatively?

- Poloidal Momentum Transport (all issues)
- basic physics \leftrightarrow drives, O.D.'s etc.
 \leftrightarrow cross-phase in vorticity flux...?
 - toroidal \leftrightarrow poloidal link $\rightarrow \langle U_E \rangle$
 and what else?
 - Perturbations, again:
 V_0 pulse from prompt torque?
- \Rightarrow understand departure of $\langle V_0 \rangle$
 from neoclassical expectations

- Neoclassical Theory / Effects (Theory Issue)
- tools developing to go beyond simple theory to cases of complicated geometry - i.e. GTGNeo
 - need interface/couple turbulence + neoclassical transport tools
 - poloidal momentum
 - transport near marginality

→ Theory and Simulation

- improve models, geometry.....
- till now, largely fluid, electrostatic

- need face/address:
 - wave transport channel (P.D.)
 - EM
 - resonant particles, EP } especially Alfvénic EP modes on BP

①

ES ⇒ WMD = NR PMD

EM ⇒ WMD = NR PMD + Field MD

② resonant particles demand precise treatment of cross-phase

③ Momentum transport from $\left\{ \begin{array}{l} \text{wave prop.} \\ \text{EM EP modes} \\ \text{EP + turb.} \end{array} \right.$ ↔ all issues for ITER

c.e. KAW → radial propagation parallel

↔ $\Pi_{r||}$ for waves

$\tilde{B}_r \rightarrow$ wave momentum transport along 'fluttering' field
 $\langle \tilde{B}_r \tilde{P}_{||} \rangle$

⇒ Last and Least - Simulation...
(especially GK)

- GK simulation has contributed little (if any) to understanding momentum transport by turbulence...
- ↕
- no where to go but up! → How?
- how extract info re: transport, especially D, V, S interplay, from δF simulation?
- how address cross-phase self-consistently?
- what might be gained from simpler models - i.e. GF?